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"Exploration in the Earth's Neighborhood" Architecture Analysis

"A Work in Progress"

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Agenda

- **Lunar Architecture**
- **L_2 Evolution**
- **L_2 Stepping Stone**

Lunar Architecture

Lunar Exploration Scenarios

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- Lunar south polar region represents an excellent initial foothold for human exploration
  - Science potential is high
  - Potential access to resources
  - Environmental conditions probably most benign on lunar surface
  - Power storage problems significantly reduced or eliminated for extended stays
- Apollo-class sortie capabilities to anywhere on lunar nearside (or farside with comm relay)
  - Focused, high value objectives requiring reduced exploration resources (crew, time,surface infrastructure)

Human Lunar Architecture Concept

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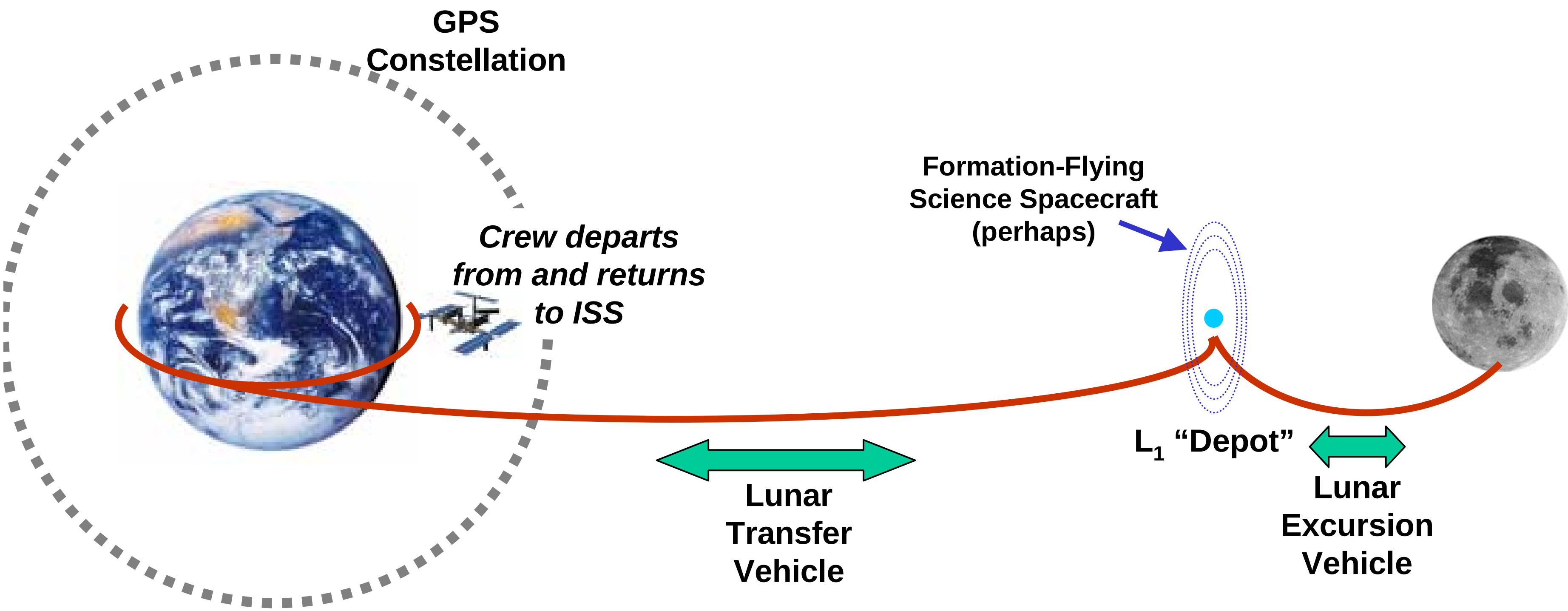

Architecture Assumptions

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- **Important considerations**
  - **Requirement for high-capacity launch capability deferred**
  - **“Safe haven” at L_1 and ISS**
- **Technology “freeze” in ’05 – assumes ISTP tech goals are met**
- **Initial LTV operations by ‘09**
- **No commitment regarding extensive lunar surface infrastructure**
  - **Transportation capabilities established allowing future expansion for science and commercialization**

Domestic ELV Options

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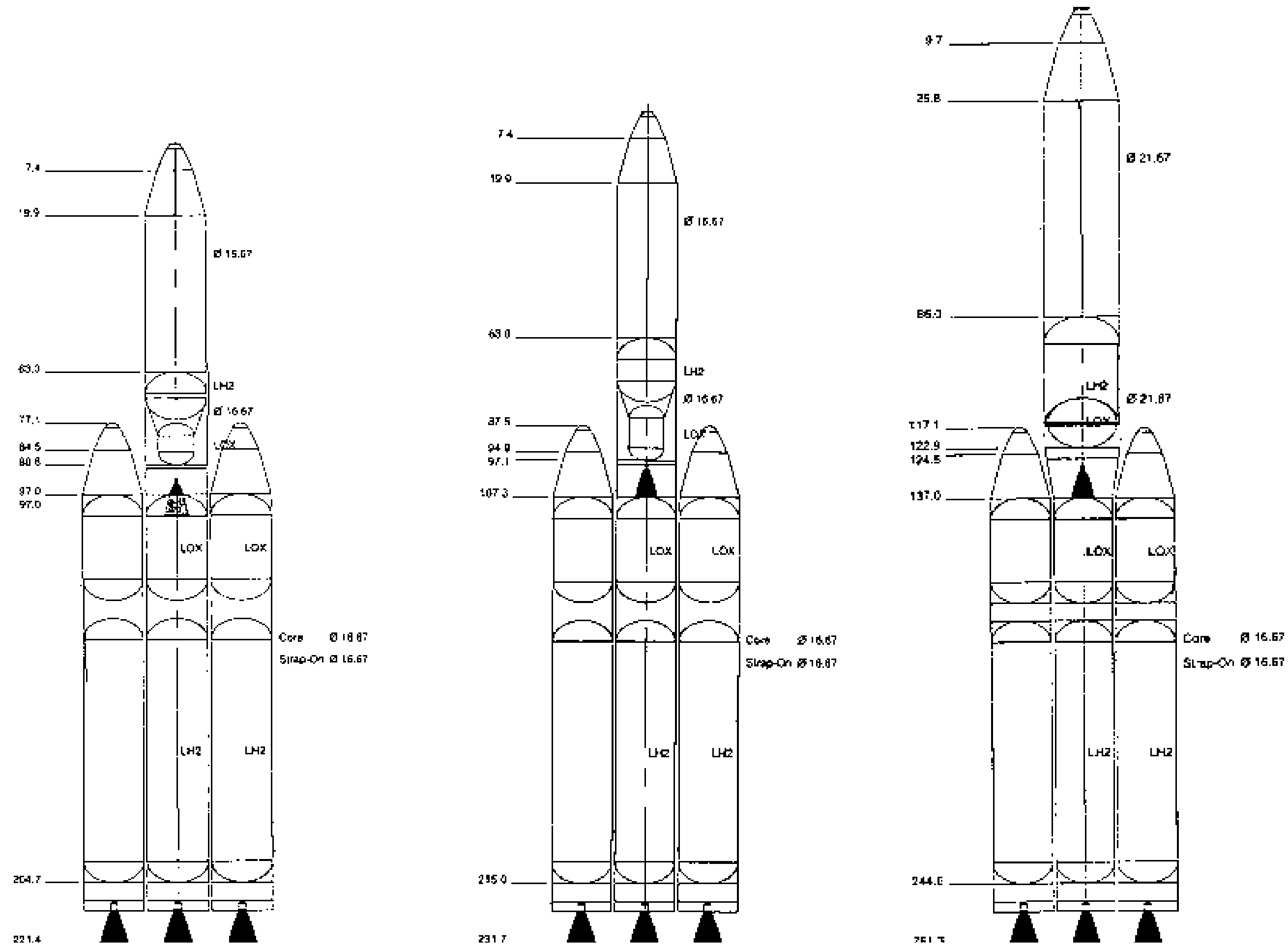

P/L to LEO	24494 kg	28991 kg	35380 kg
PRICE	$135M	$140M	~$155M
IOC	02/03	~05	TBD

BOEING PROPRIETARY

Architecture Elements

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- L_1 "Gateway"
- Lunar Transfer Vehicle (LTV)
  - Human transport from ISS to L_1 Depot and return
- High-Energy Injection Stage
  - Initial boost for LTV
- Lunar Excursion Vehicle (LEV)
  - Human transport from L_1 Depot to lunar surface and return
- Solar Electric Transfer Vehicles (SETV)
  - Delivery of L_1 Depot and LEVs to L_1

Lunar Transfer Vehicle

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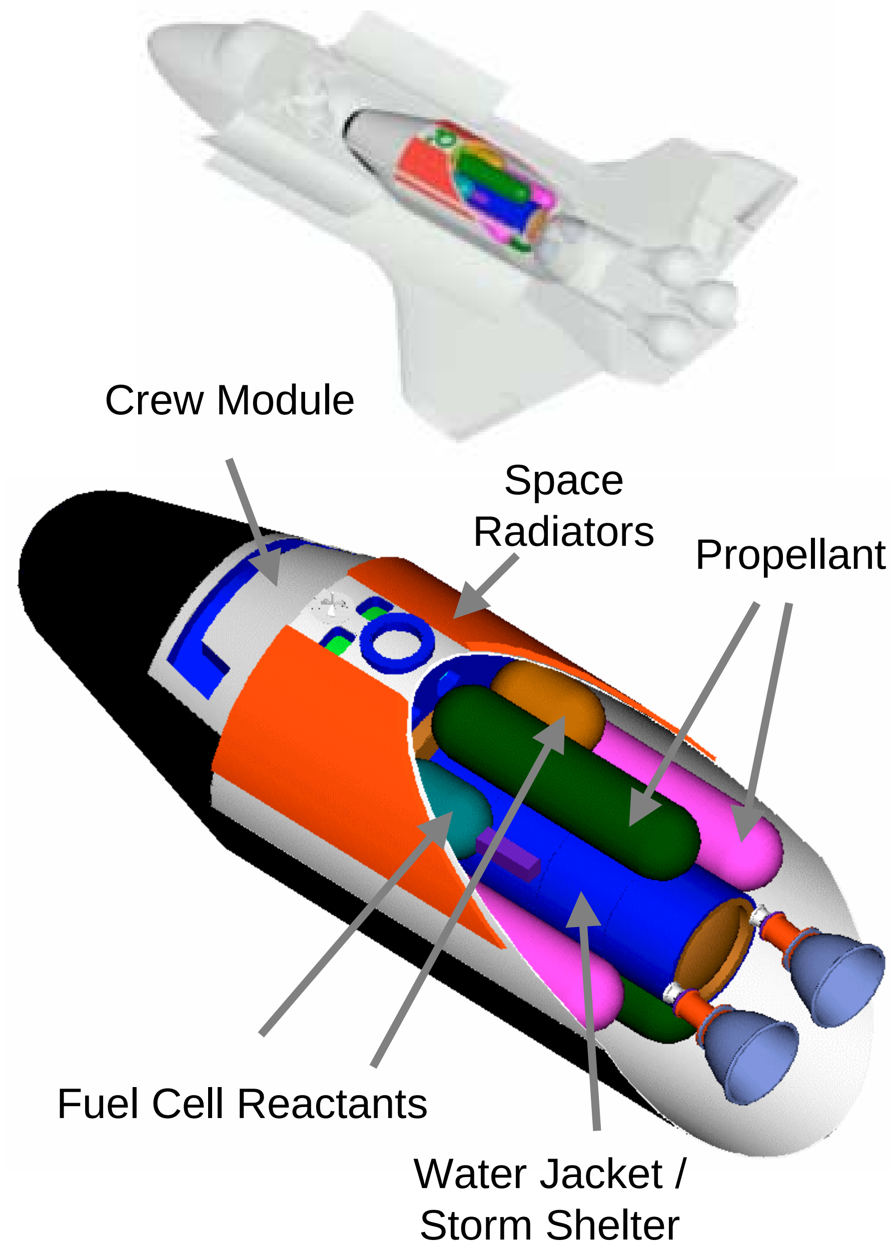
- **"Requirements"**
  - **Based at ISS for timing flexibility**
  - **Launch and recovery in Space Shuttle**
  - **Utilizes space storable propellants**
  - **Crew of 4 with ΔV capability of >1700 m/s**
  - **Operations in automated mode, or with crew onboard - automated rendezvous and proximity operations**
  - **Aerocapture manuevers at lunar return speeds to ISS orbit**
- **Preliminary Concept**
  - **Lifting body for crew g reduction**
  - **Integral LOX/CH_4 propulsion system**
  - **Eighteen day independent mission capability**
  - **Lightweight docking system**



High Energy Injection Stage

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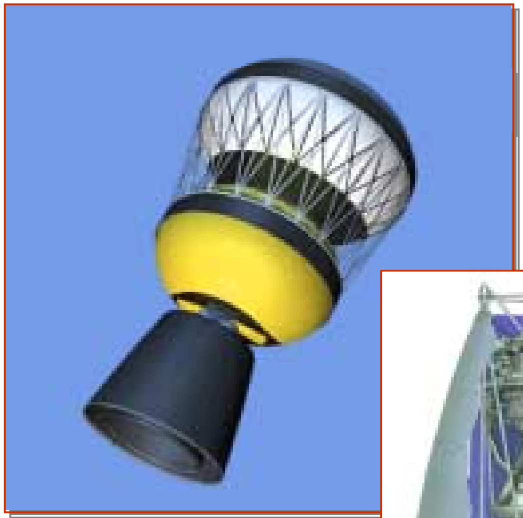
- “Requirements”
  - Launch on EELV / Shuttle
  - Sufficient performance that when combined with fuelled Lunar Transfer Vehicle, missions to L_1 and return
  - Capability to achieve vicinity of ISS and maintain for > 30 days after launch
    - Rationale Lunar Transfer Vehicle and crew at ISS, represents two missed lunar injection opportunities
  - Ability to be structurally docked to Lunar Transfer Vehicle
- Preliminary Concepts
  - Derivative of Delta IV 5.1-m Configuration Stage
    - LOX/LH2, P&W RL10B-2
    - On-orbit life extension via small solar array (size TBD)
    - Propellant storage via cryo-cooler or propellant densification



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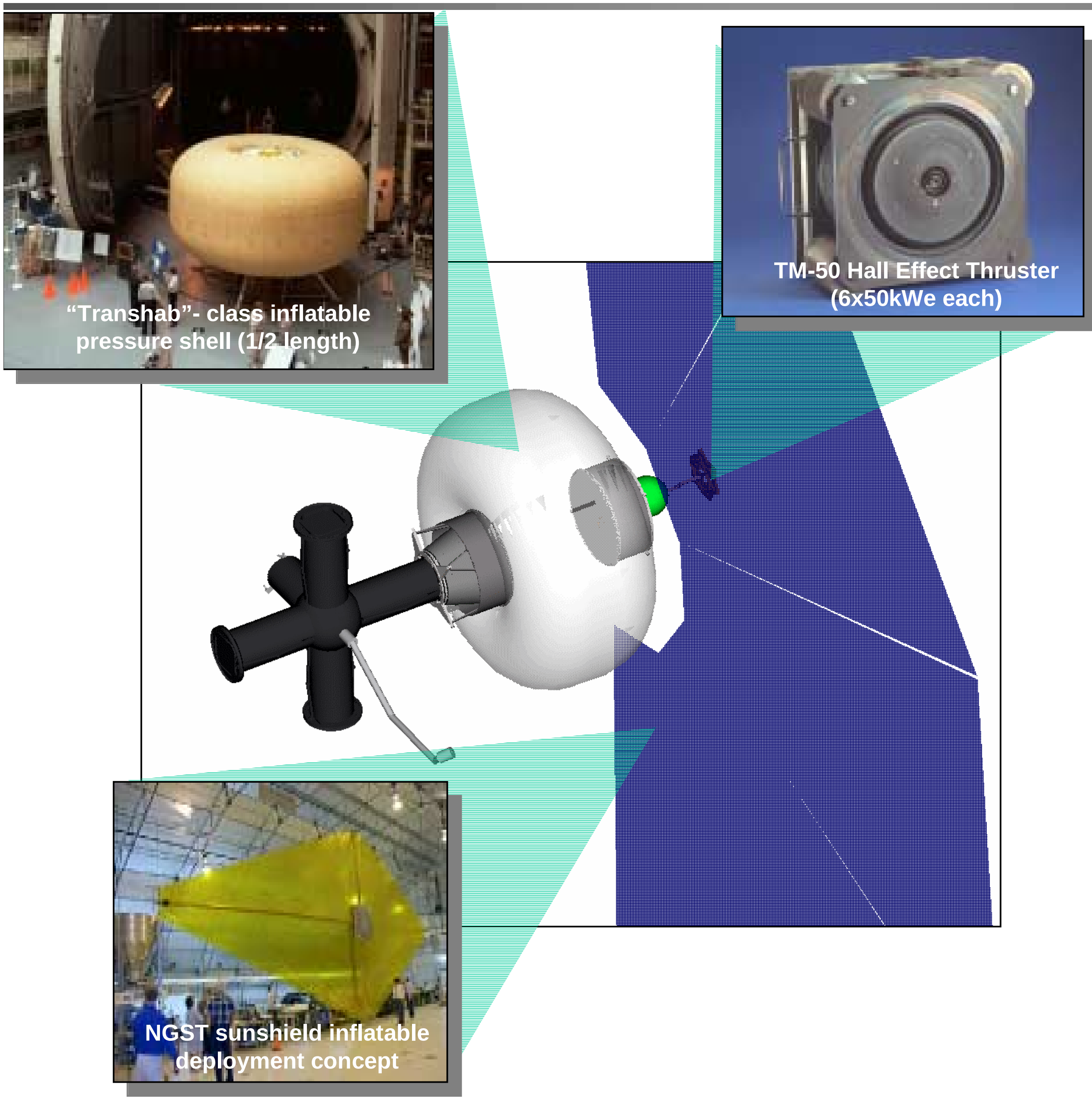
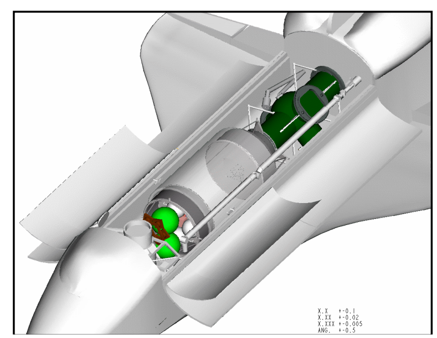
Lunar L_1 "Gateway"



- **"Requirements"**
  - Docking capability for Lunar Transfer Vehicle and Lander and pressurized crew transfer
  - Crew habitation for ≥12 days per lunar mission for return phasing or advanced system testing
  - Vehicle support (power, att. control) for Lunar Transfer Vehicle and Lander
  - Launch on EELV or Shuttle
  - Habitat delivered via solar electric propulsion from LEO to L1
- **Preliminary Concept**
  - "Half-length" inflatable habitat
  - Delivered to L_1 via Solar Electric Propulsion System
  - SEP remains attached to provide power, attitude control



Lunar Excursion Vehicle

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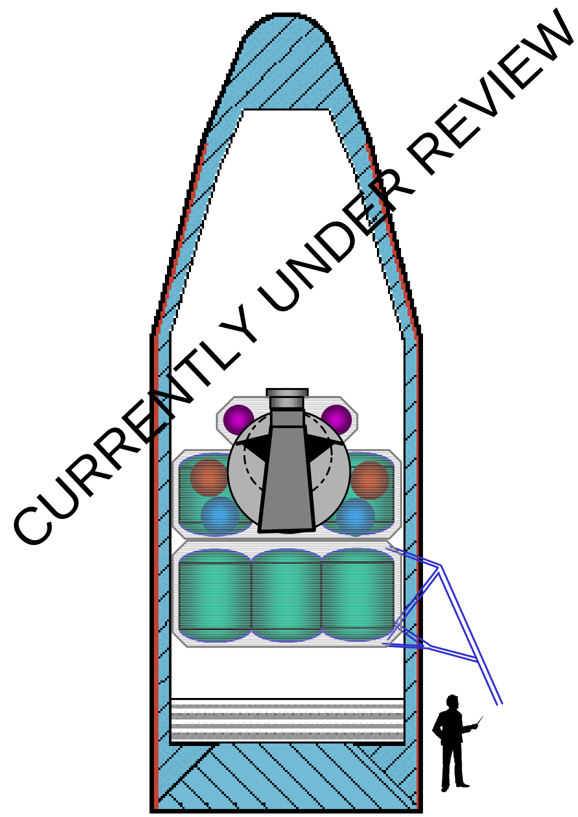
- "Requirements"
  - LEV will be designed for round-trip piloted missions from L_1 to lunar surface and back to L_1
  - LEV will be delivered to L_1 by transfer stage
  - LEV will be able to remain at L_1 for extended period to allow for delay in crew arrival
  - LEV will interface with L_1 Depot
  - LEV will allow easy lunar surface egress/ingress of suited crewmembers
- Preliminary Concept
  - LOX/CH_4 propulsion stages (ascent and descent)
  - Seven day independent mission capability



Mission Concept

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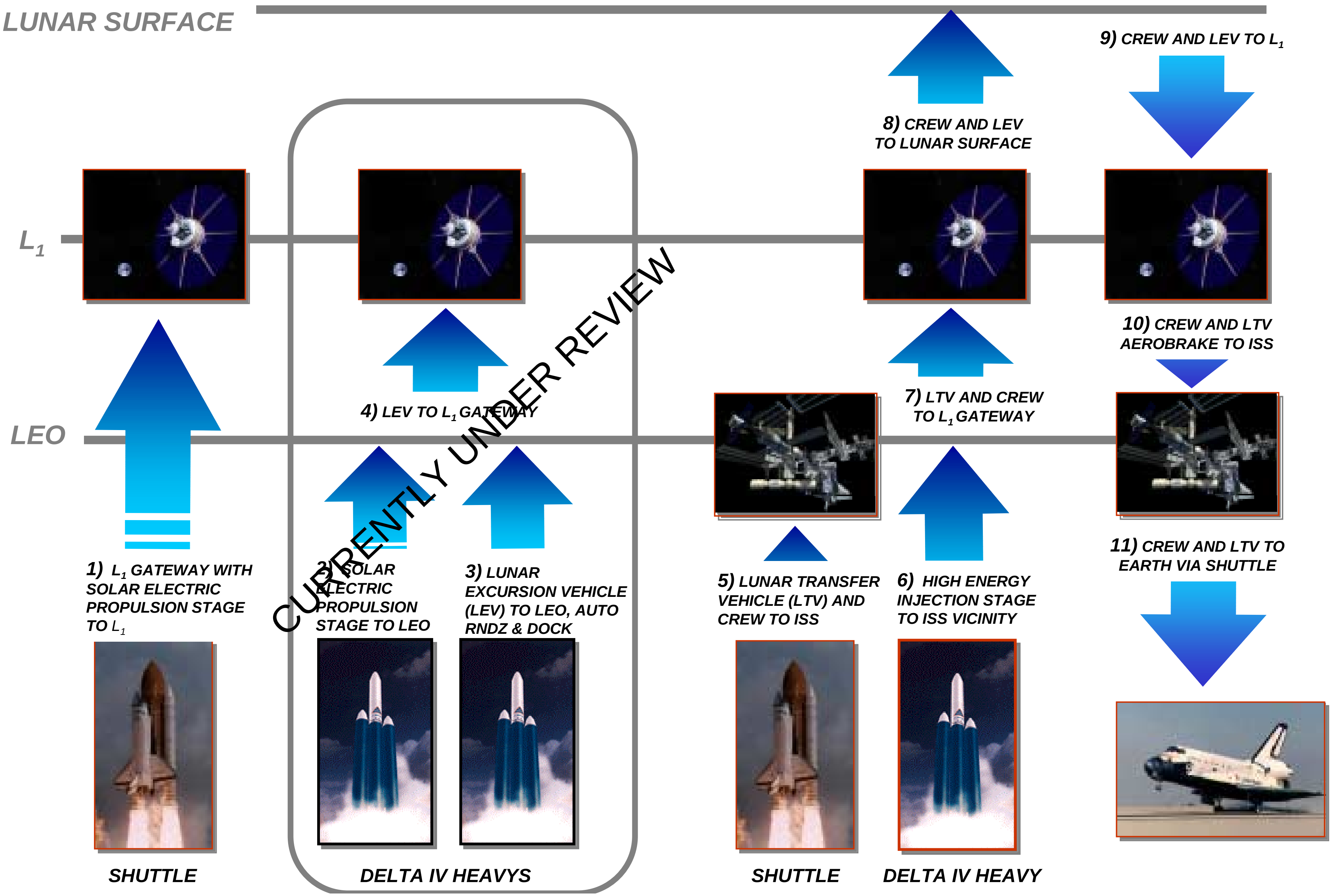

ISS Support - Why?

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- **LTV Reusability**
  - **Direct entry and landing would probably take one of two forms**
    - **"Apollo-style" - most of vehicle discarded to achieve reasonable recovery system masses (drogues and parachutes)**
    - **"Lifting-body style" - aerosurfaces, control surfaces, landing gear or drogue/parafoil/skids**
- **Launch "Decoupling"**
  - **Best efforts still imply two launches for L_1 mission - STS for Lunar Transfer Vehicle and crew, EELV for high-energy injection stage**
  - **First launch establishes orbital angular momentum, injection to L_1 must be nearly in-plane which occurs ~every ten days**
  - **On-orbit wait without depleting STS Orbiter or Lunar Transfer Vehicle life-support, attitude control, and power**
  - **"Space storable" propellant used for Lunar Transfer Vehicle**
  - **Bottom line: with ISS, LTV and lunar crew are "stable" on-orbit, only one launch coupled to trans-lunar injection window (injection stage)**
- **Reduce Vehicle Mass**
  - **By eliminating supersonic, transonic, subsonic flight and landing, the following systems are eliminated (and do not need to be taken to L_1 and back):**
    - **Aerosurfaces, control surfaces, EMAs, landing gear**
    - **Drogues, parachutes, parafoils, airbags**
- **Operations**
  - **Landing site weather not an issue for LTV return (would have to be predicted four days in advance)**

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Issues with Utilizing ISS

- No “anytime return” from L_1 or L_2 - discreet return windows
- Support for lunar/L_2 crewmembers at ISS while waiting for injection window (life support, crew return, etc.)
  - Additional capabilities or impact to ISS crew size?
  - Potential impacts to ISS science ops

Lunar Capabilities

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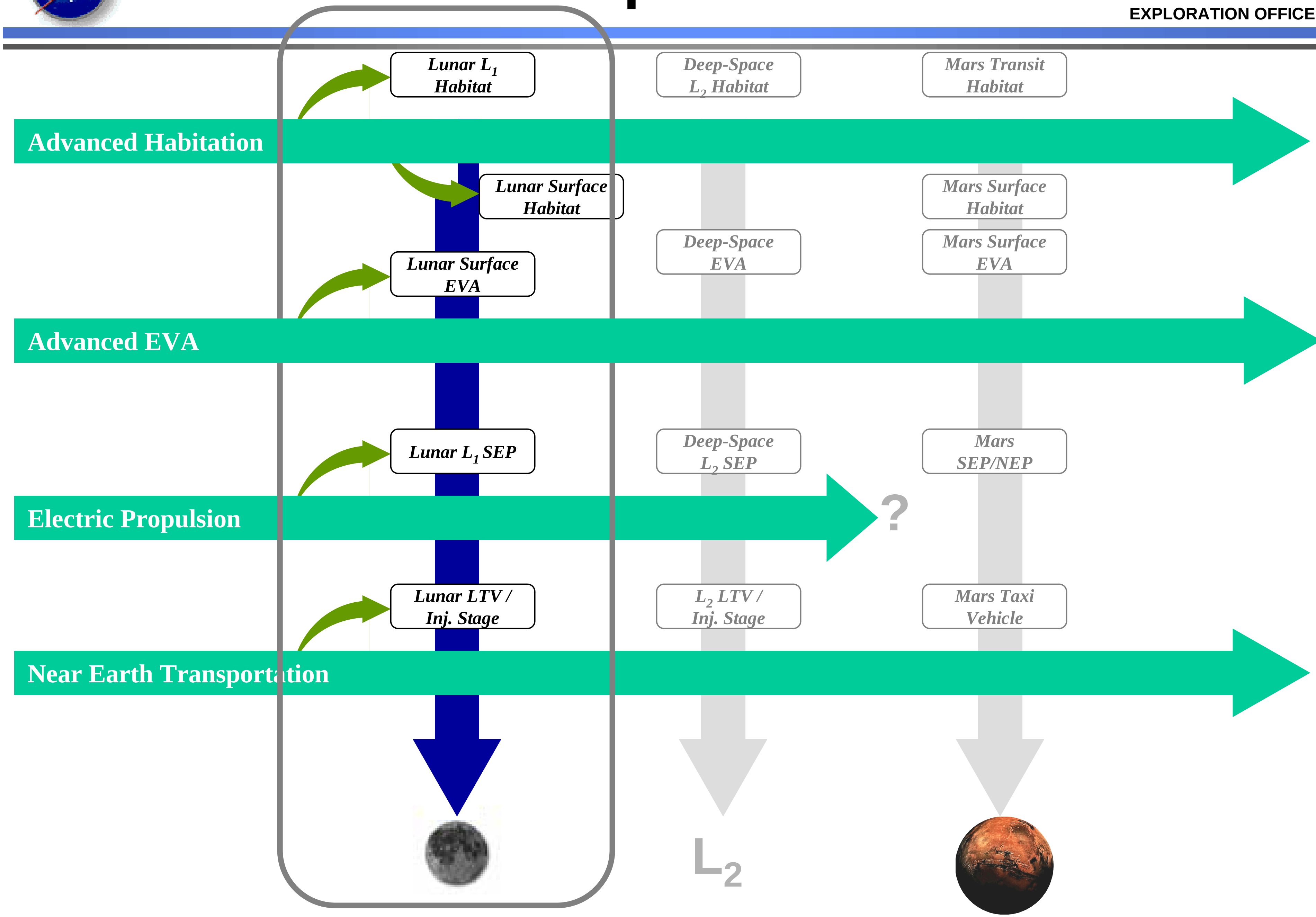

Future Work

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- **Lander definition and operational scenario**
- **Gateway system definition and outfitting requirements**
- **Gateway logistics and resupply strategy**

L_2 “Evolution” Architecture

Architecture Assumptions

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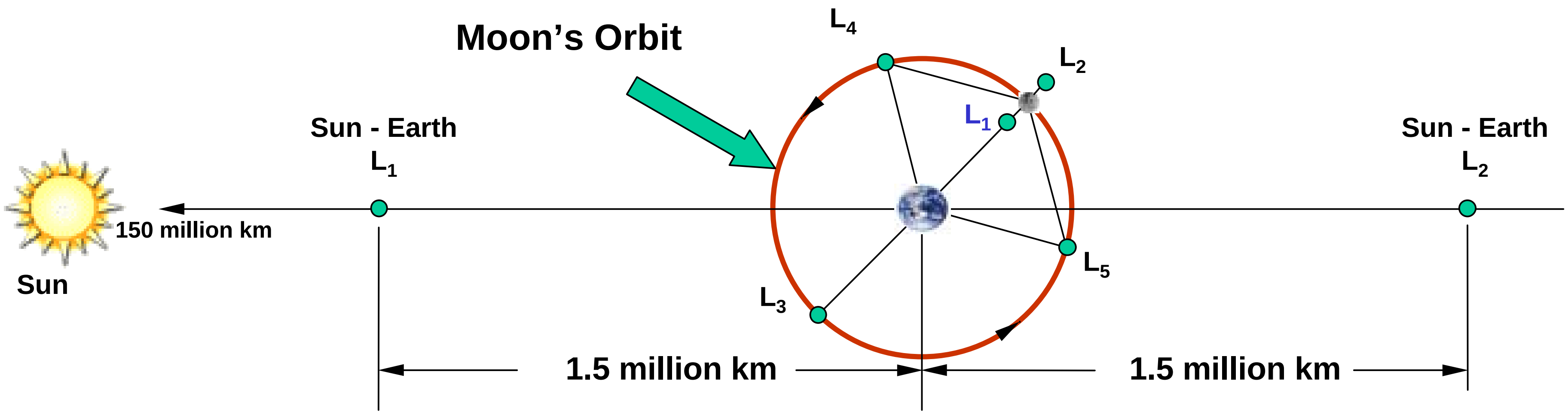
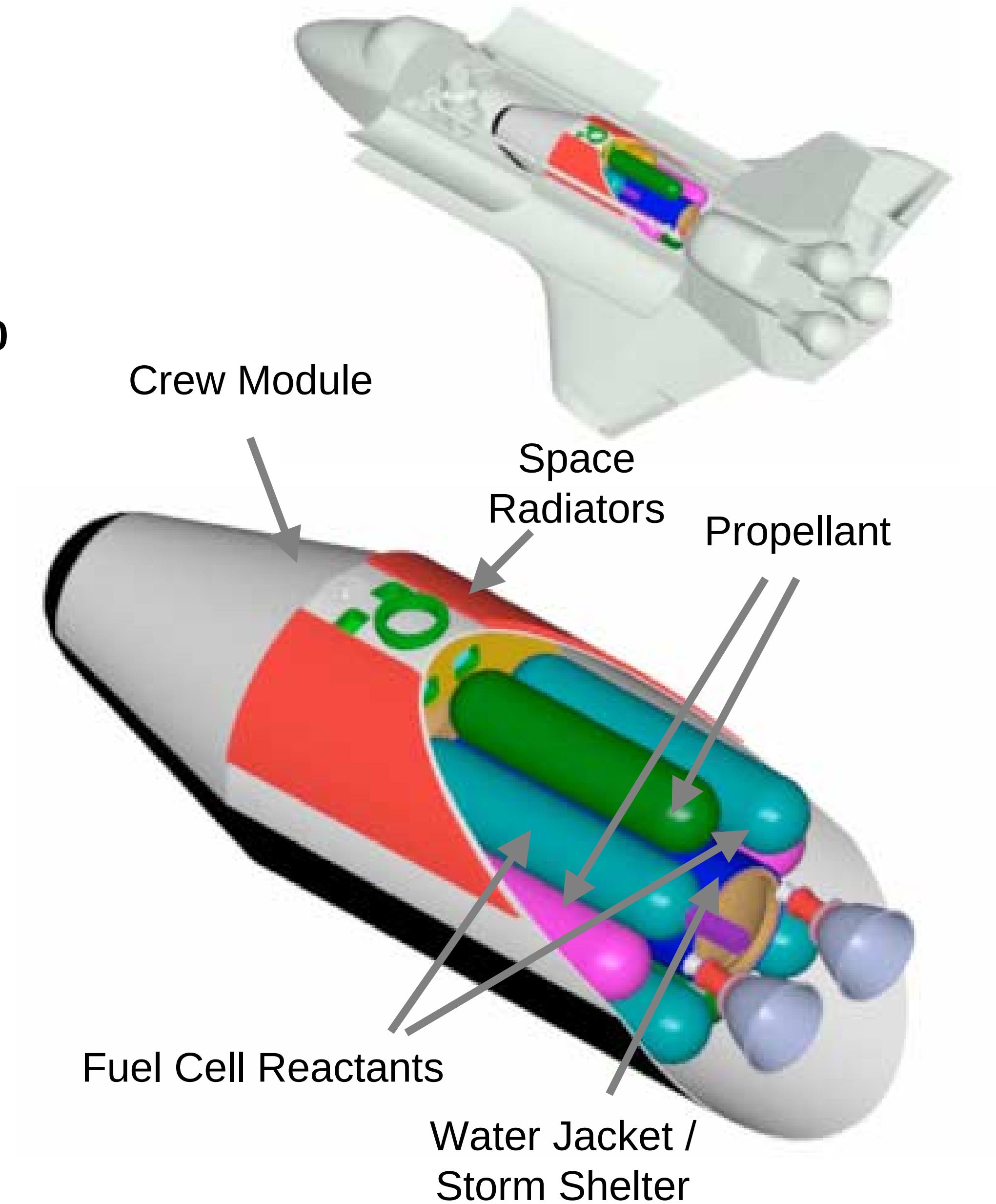


- **Similar approach taken as for lunar architecture**
- **L2 Gateway**
  - **Delivered to E-S L_2 via SEP, remains in L_2 vicinity**
  - **Provides extended life-support and EVA support for operations**
  - **Provides power, attitude control, etc. to Transfer Vehicle**
- **L_2 Transfer Vehicle**
  - **Volumetrics associated with 18-day 4-person lunar capability should suffice for trans-L2 and trans-earth mission phases**
  - **Extended power storage and consumables to support maximum of 70-day contingency mission (unable to dock with Gateway)**

L_2TV Transfer Vehicle

- **“Requirements”**
  - –Based at ISS for timing flexibility
  - –Launch and recovery in Space Shuttle
  - –Utilizes space storable propellants
  - –Crew of 4 with ΔV capability of >1700 m/s
  - –Operations in automated mode, or with crew onboard - automated rendezvous and proximity operations
  - –Aerocapture manuevers to ISS orbit
- **Preliminary Concept**
  - –Lifting body for crew g reduction
  - –Integral LOX/CH_4 propulsion system
  - –65 day independent mission capability
  - –Lightweight docking system



High Energy Injection Stage

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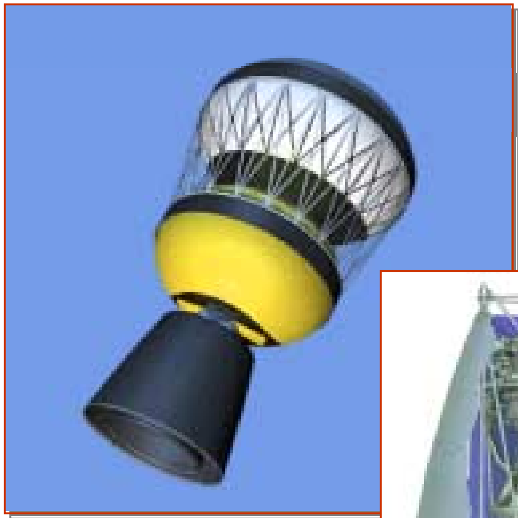

L_2 Gateway

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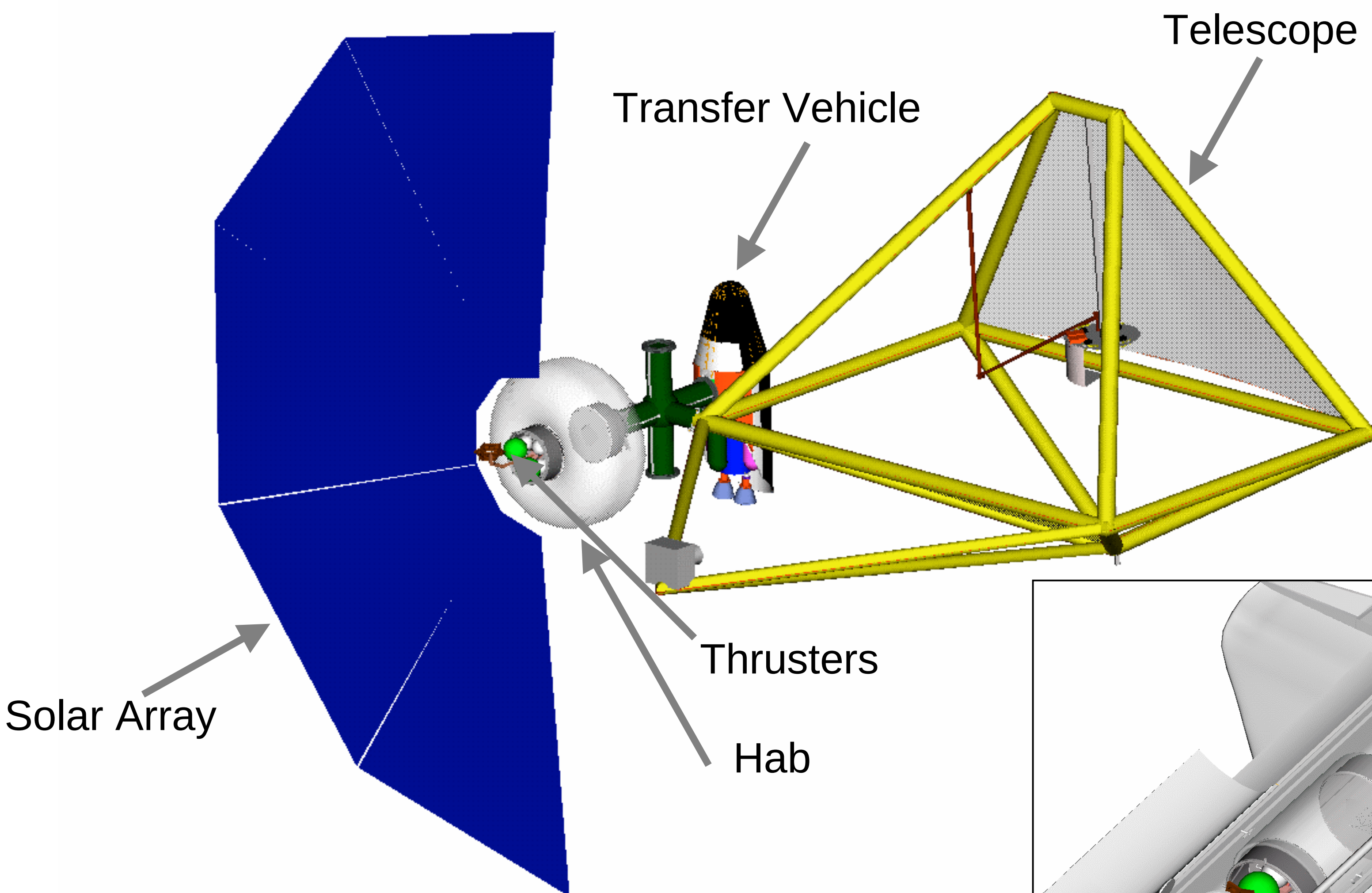

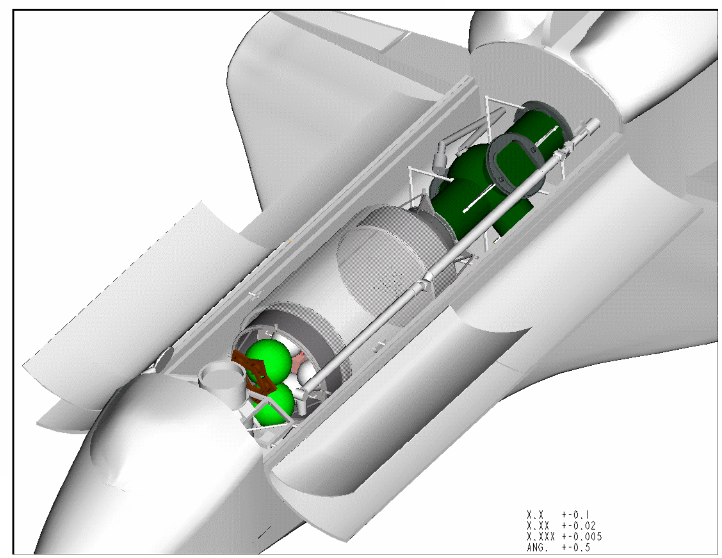

Mission Concept

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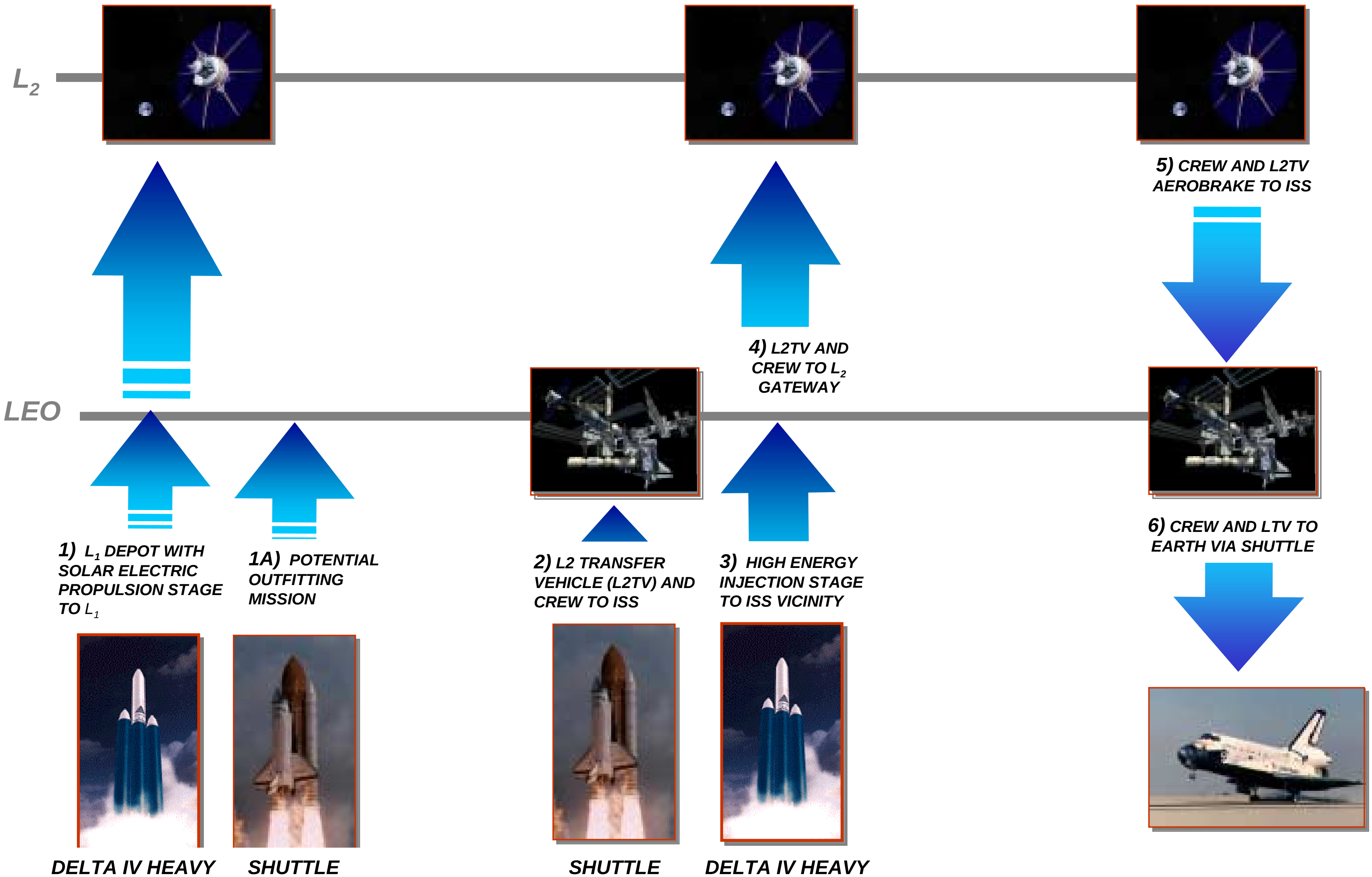

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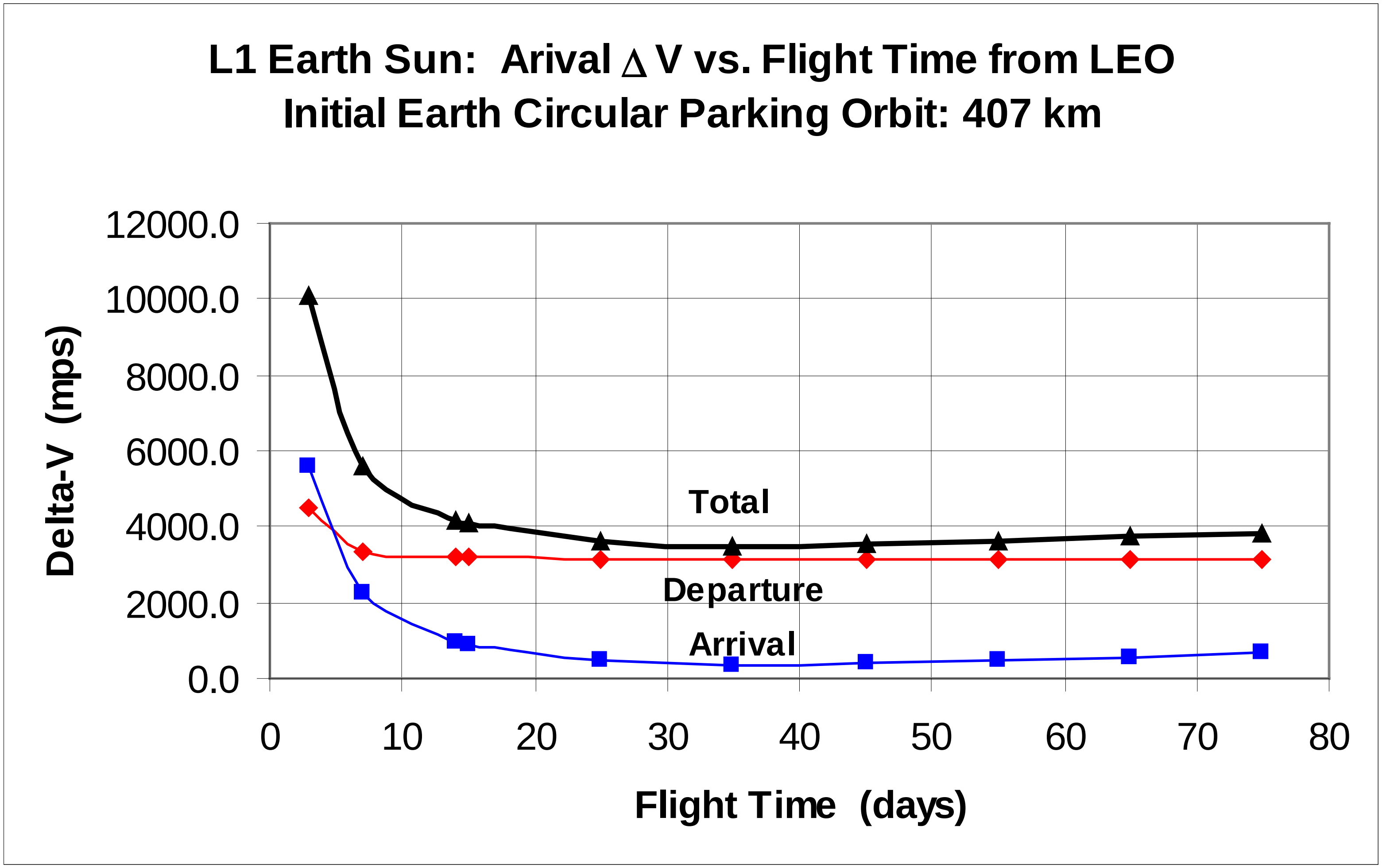

Sun-Earth Libration Point (L2) Mission Opportunities

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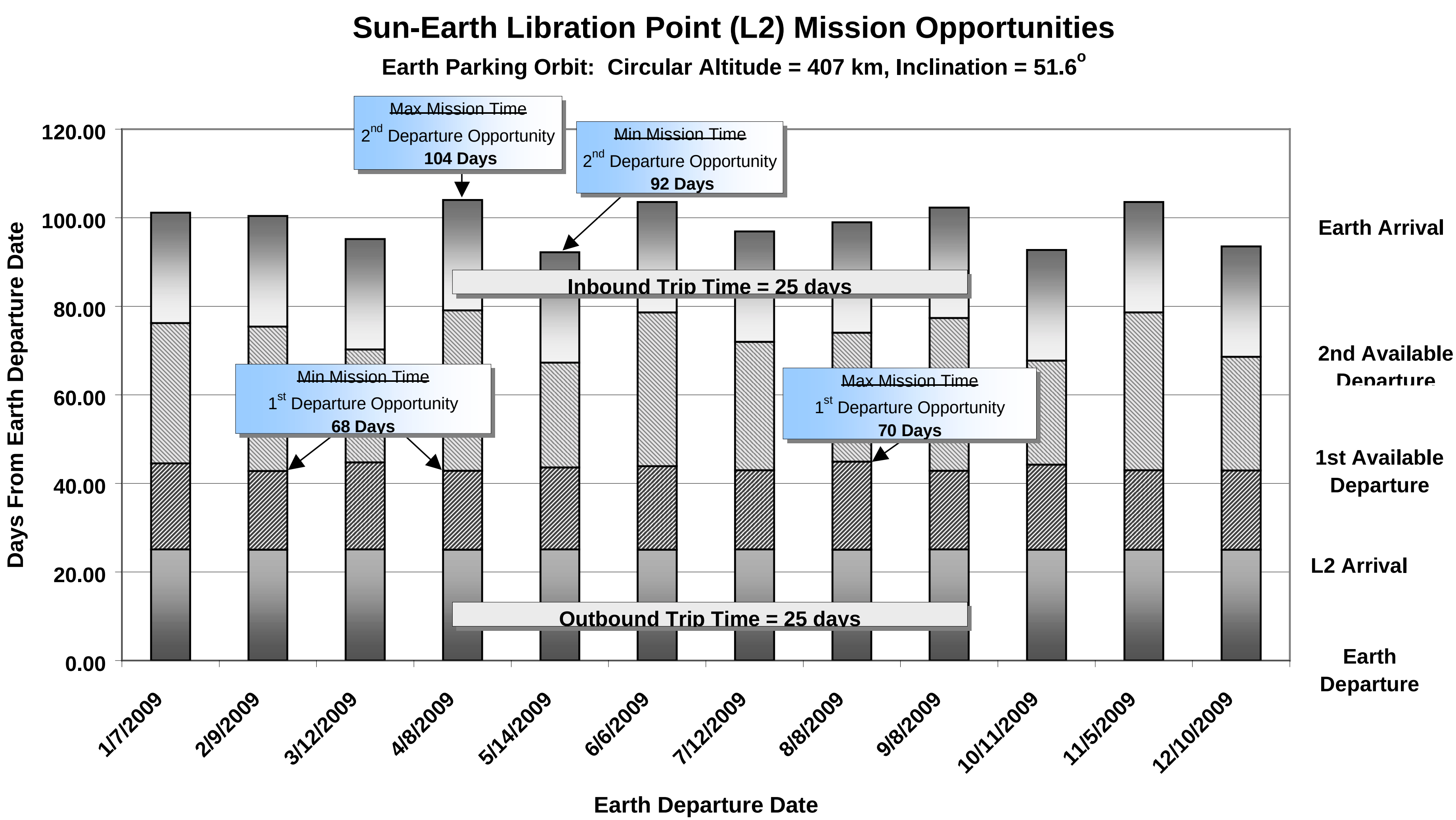

L2 “Evolution” Capabilities

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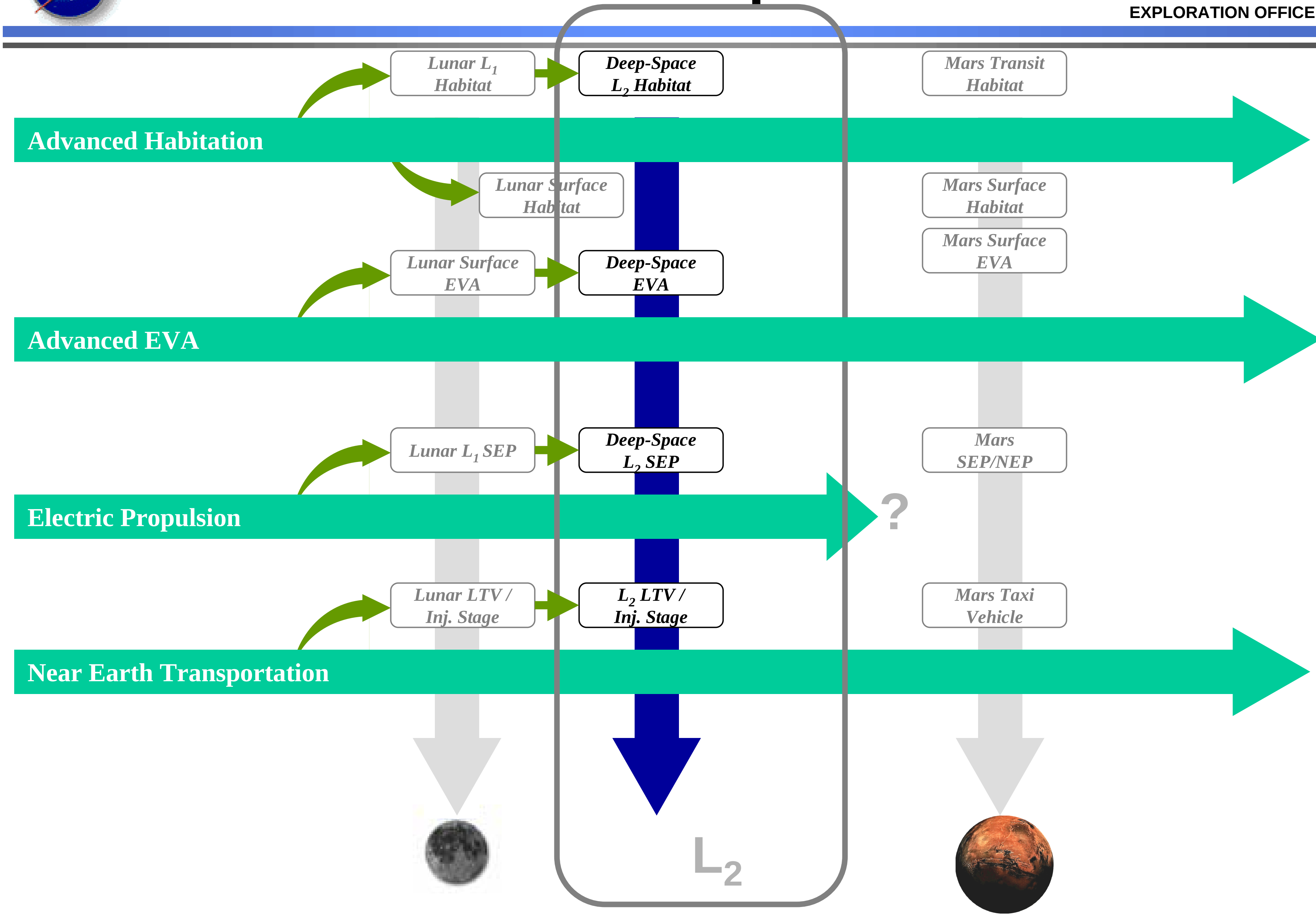

L_2 "Stepping Stone" Architecture

L_2 Architecture Options

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- **Two architecture options being examined**
- **L_2 "Evolution"**
  - **L_2 science operations primary requirements and schedule driver**
- **L_2 "Stepping Stone"**
  - **Human Mars mission primary requirements driver**
  - **Approaches, technologies, schedule reflect emerging Mars exploration architecture**
- **Primary differences due to eventual Mars architecture:**
  - **L_2 Gateway and scale of L_2 capabilities (crew, duration) may be much more robust in "Stepping Stone" approach**
  - **Gateway becomes "Mars Transfer Vehicle" (MTV) hab**
  - **Extensive testing of MTV systems in interplanetary environment (L_2)**

L2 "Stepping Stone" Capabilities

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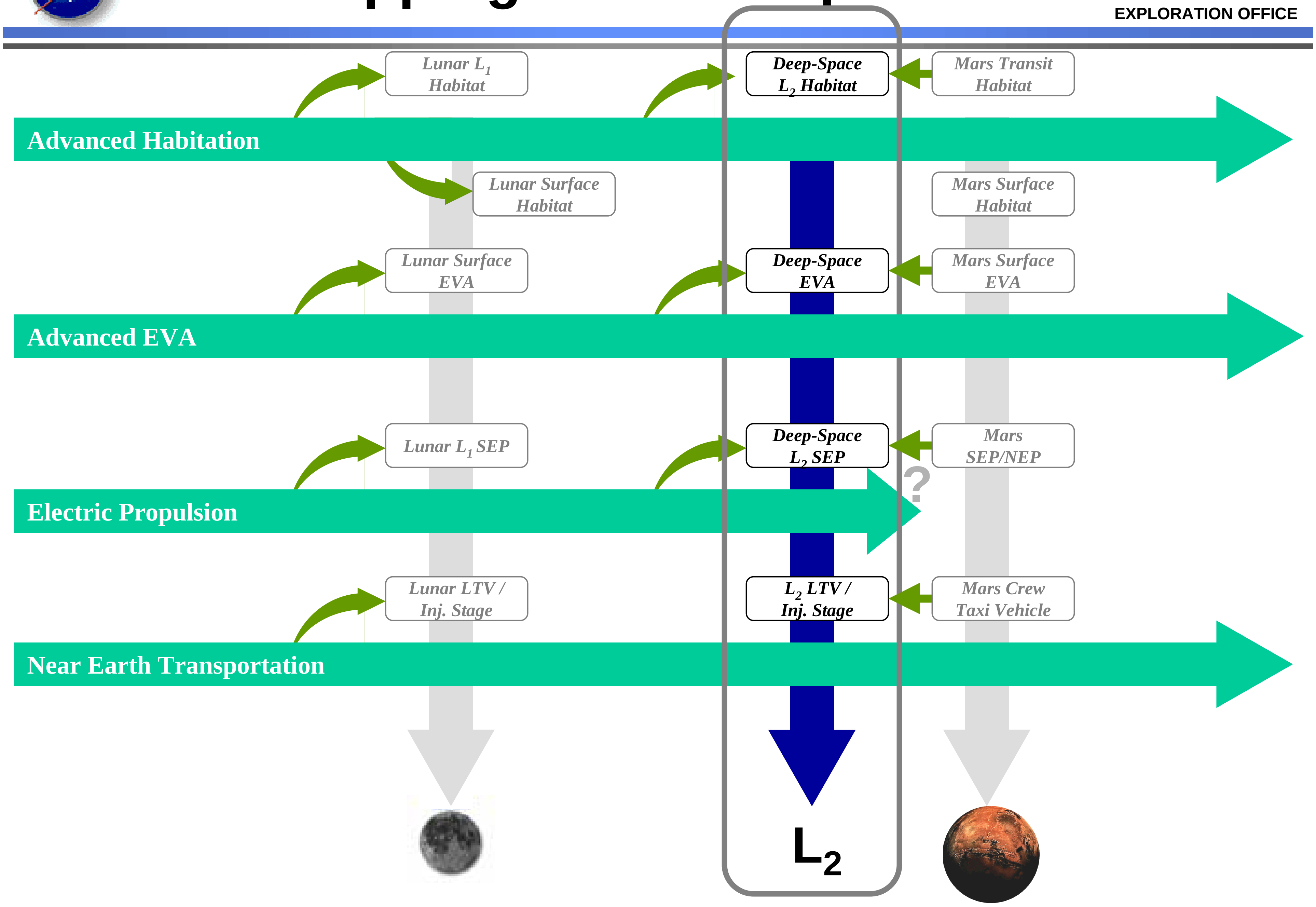

Issues

- **Crew Radiation Protection**
  - **Solar proton events**
    - **Current strategy is to provide water-jacketed "storm shelter" (both in transfer vehicles and gateways)**
    - **Strategy may not work for lunar landers (mass penalties), however, two-day transit to gateway should be within SPE prediction capability**
  - **Galactic cosmic radiation**
    - **Risk increases with mission duration**
    - **Risk increases with secondary particle production via interaction with surrounding material – *materials selection and vehicle geometry is key***
    - **Risk has to be assessed in context of crew exposure in various environments (EVA, spacecraft, gateways)**
    - **Research required for:**
      - **Biological effects (JSC) – on Life Sciences critical Path Roadmap**
      - **Materials interaction (LaRC, JSC)**
      - **Environment definition (Codes S, U, M)**

Future Work

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- More detailed EVA system definition and operational scenarios
- Gateway system definition and outfitting requirements
- Gateway logistics and resupply strategy

Backup

The Role of Lunar Exploration

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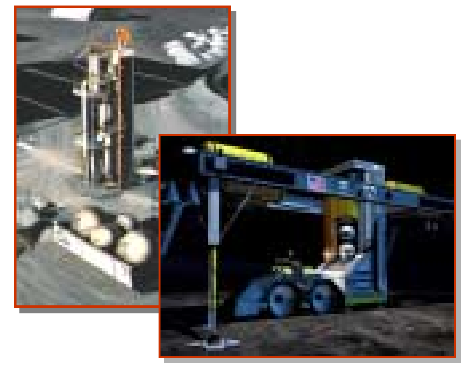
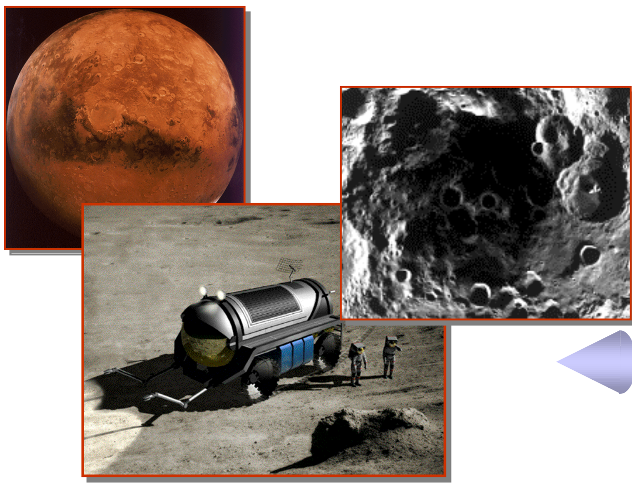
*Development of Core Capabilities**

- Advanced Systems
- Advanced Technologies

*Commercial Potential**

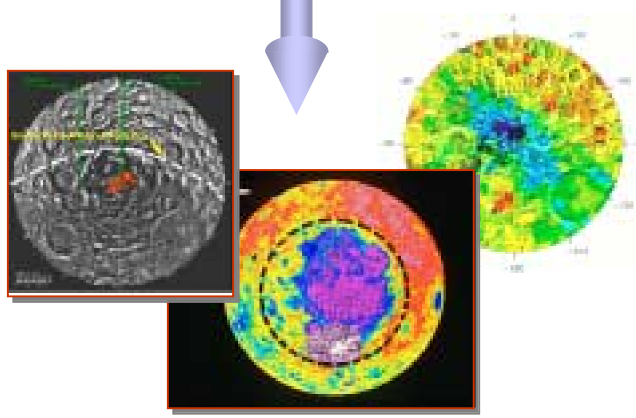
- Lunar Oxygen or Water Production
- Regolith Materials Processing





Operational Experience

- Autonomous Deep Space Operations
- Planetary Surface Operations
- Mars Analog at Lunar Pole



*Science Return**

- Impact History in Near-Earth Space
- Composition of Lunar Mantle
- Past and Current Solar Activity
- Lunar Ice at Poles - History of Volatiles in Solar System

***Draft, HEDS Strategic Plan**

Earth-Moon L_1 Characteristics

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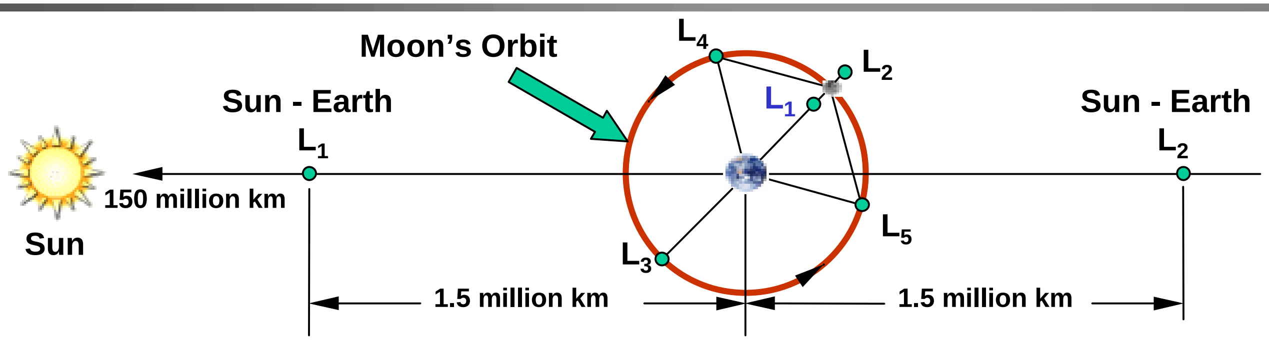
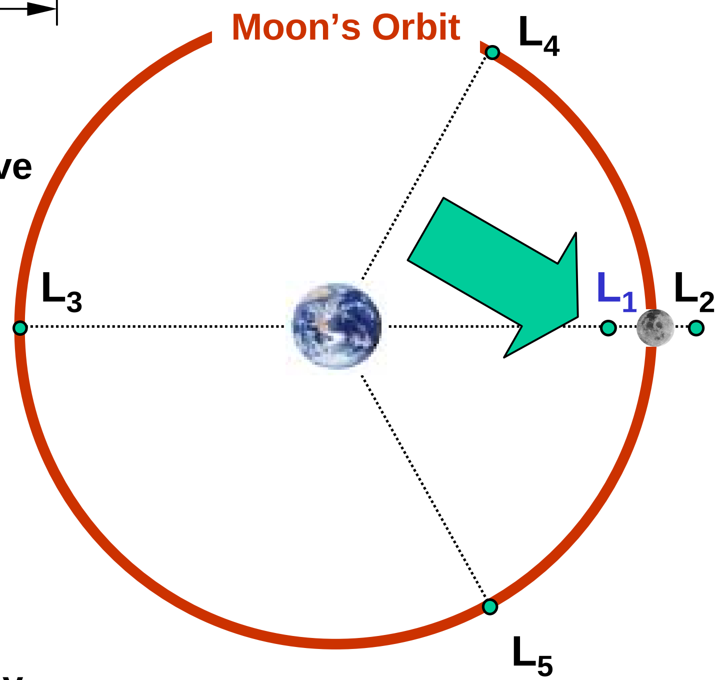


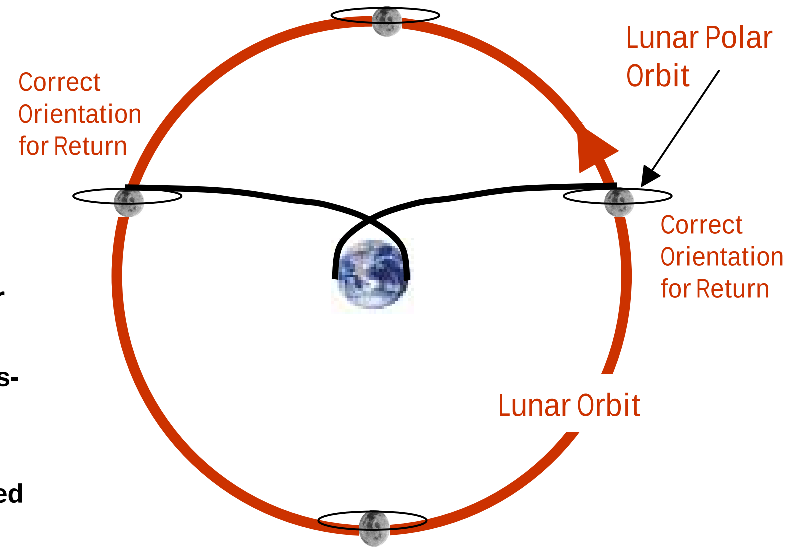
- Environment
  - No orbital debris. Weak instability of L_1 will actively remove artificially created debris.
  - Nearly continuous solar energy (>99.91%), no thermal cycling
  - Nearly continuous full sky viewing (>99.96%)
  - True deep space radiation, thermal environment, zero-g
  - Continuous view of Lunar nearside, Earth, terrestrial magnetosphere
  - No atmospheric drag
- Operations
  - Excellent transportation node for lunar surface, particularly polar regions
  - Four days from Earth, two days from Moon (high thrust)
  - Formation flying spacecraft mutually accessible with minimal delta-v, slow relative motion
  - Potential staging point for deep-space exploration missions

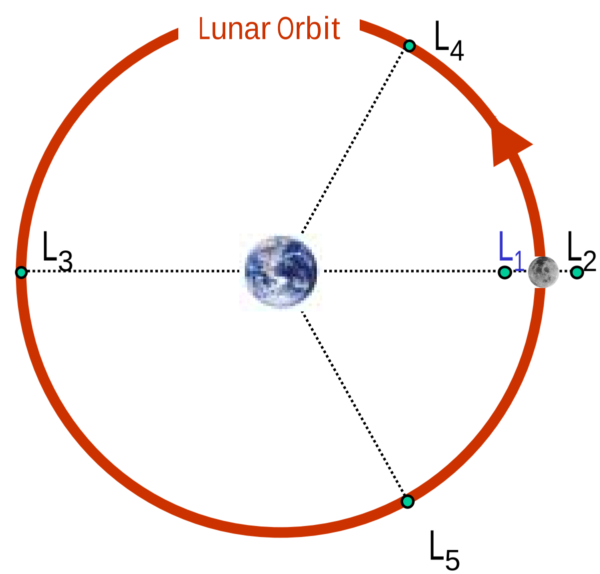


	Distance from Earth's Center (km)	Distance from Moon's Center (km)
L_1	326740	57660
L_2	449748	65348
L_3	380556	764956
L_4	384400	384400
L_5	384400	384400

L_1 Staging - Why?

- **Operational Considerations**
  - **Lunar Orbit Rendezvous (LOR)**
    - **Access to lunar poles would require polar orbit if LOR mission mode utilized**
    - **Lunar polar orbit provides infrequent opportunities for trans-Earth injection (once every 14 days)**
      - **Orbit orientation inertially fixed, aligns with efficient trans-Earth trajectory twice a month**
    - **Access to ISS orbit would probably be impractical**
      - **Trans-Earth trajectory would *also* need to be synchronized with ISS orbit regression**
    - **Little control over Earth landing location without aerocapture and phasing**
    - **Total ΔV = 9461 m/s**
  - **Libration Point Rendezvous**
    - **Continuous access from L_1 to lunar surface and return**
      - **Lunar rotation and libration point motion naturally synchronized**
    - **Continuous access to Earth - landing point partially controllable**
    - **Access to ISS orbit every ten days**
    - **Total ΔV = 10746 m/s**
- **Unique science opportunities may exist at L_1**
- **Deep-space human exploration analogs exist at L_1**
- **Support for deep-space human exploration missions at L_1 may advantageous**





Mission Constraints

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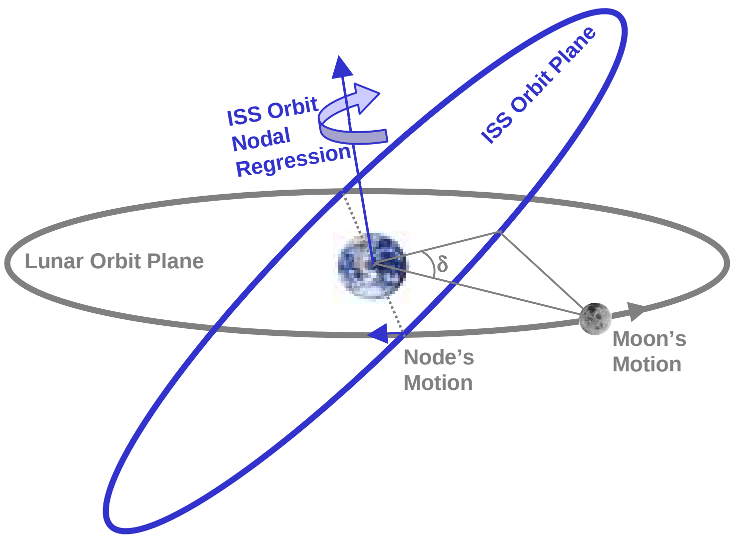

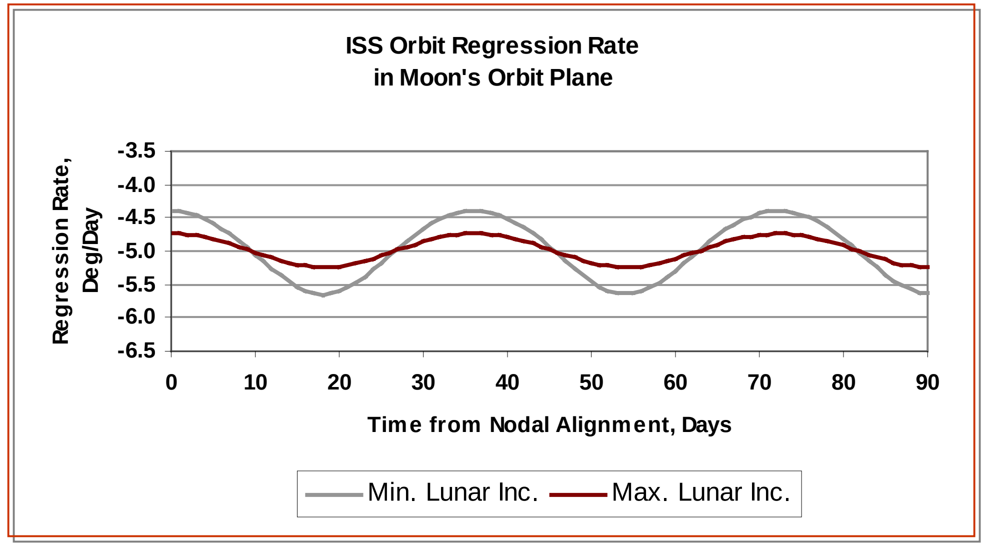

- Injection Windows from ISS to L_1
  - Combination of ISS Nodal Regression and Lunar Motion provides injection opportunity every ten days
- Injection Windows from L1 to Moon Continuously Open
  - Apollo-type landing lighting constraints eliminated if polar location chosen
  - L_1 Synchronized with Lunar Surface
- Symmetry in Return to ISS

Lunar Rate=	13.1764	deg/day
Orbit Regression Rate=	-4.984	deg/day
Alignment Interval=	9.912	days
Trip Time=	4.125	days
TLI=	2.993	days prior to nodal alignment
TEI=	1.132	days prior to nodal alignment

Event	MET days	MET DD:HH
TLI	0.000	00:00
Nodal Alignment	2.993	02:23
L1I	4.125	04:03
TEI	11.772	11:18
Nodal Alignmenet	12.904	12:21
EOI	15.897	15:21

Lunar Polar Characteristics

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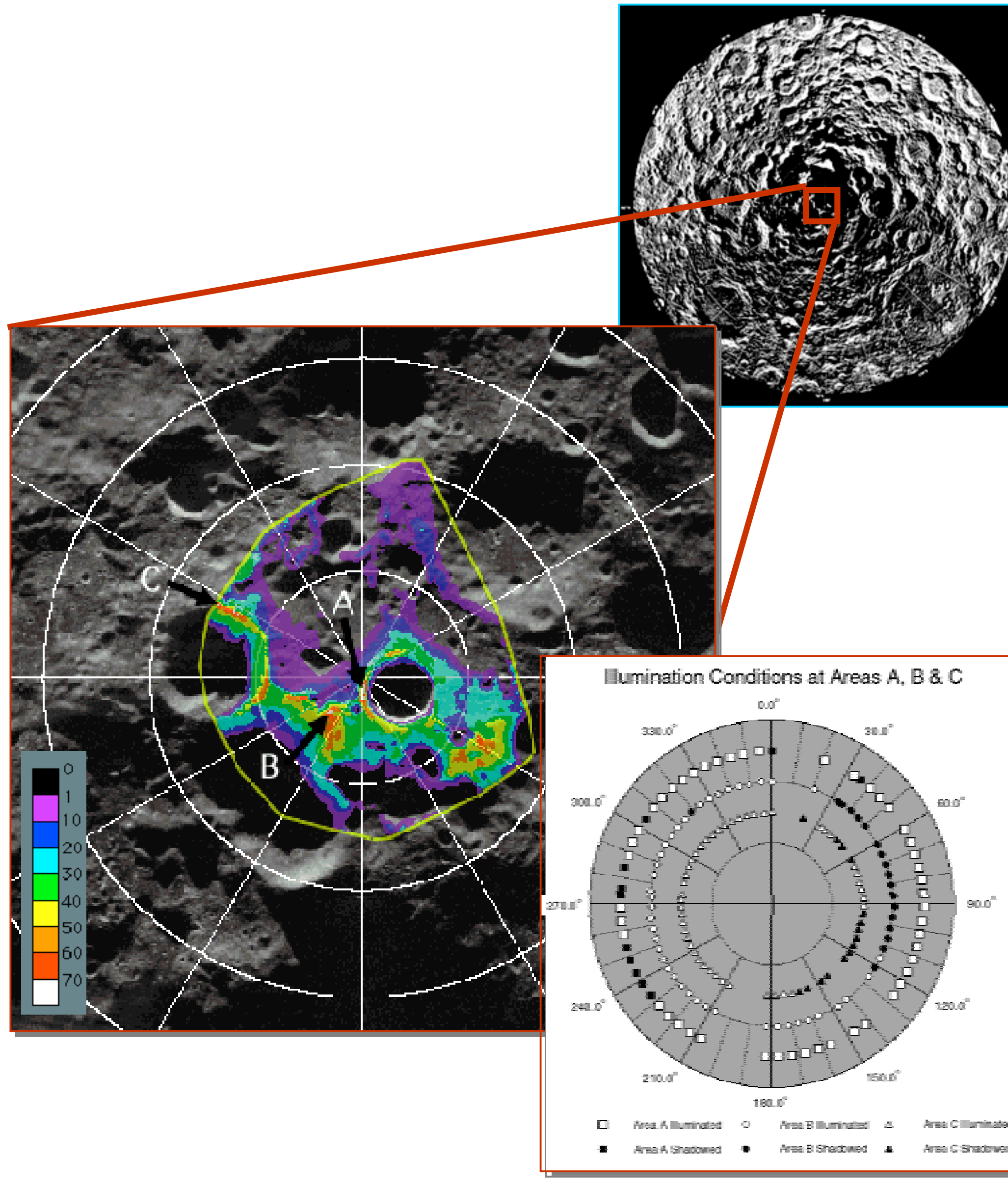
- **Terrain in south polar sites may provide nearly continuous sunlight (>80%)**
- **Low sun elevation provides nearly constant surface temperatures (-50ºC vs. -170º to +120ºC at equator)**
- **Region proximate to large permanently shadowed areas (-230ºC) and potential location of ice deposits**
- **Site is within largest impact basin known in solar system. Lower crust/upper mantle of Moon exposed here or nearby.**
- **Complete and continuous view of southern sky**
- **Terrain masking from terrestrial radio sources**



After D.B.J. Bussey, et. al., 1999

Potential Lunar Polar Science Missions

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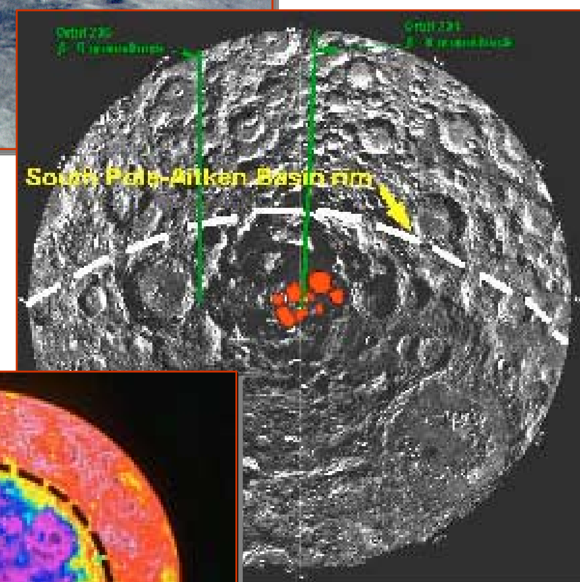
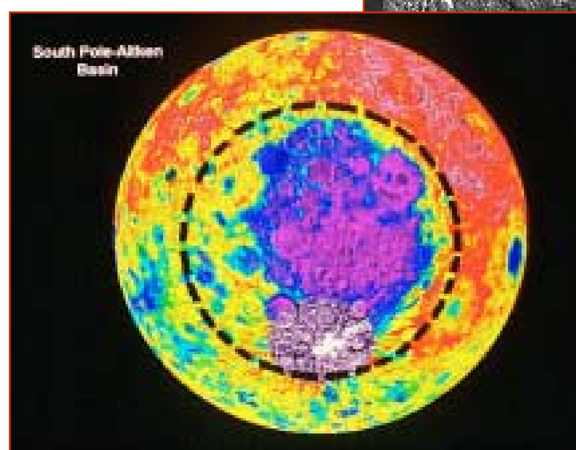
- **The Moon can be thought of as a 4.5 billion old impact detection instrument**
  - **Unique record of impact history in near-Earth space**
  - **Crater dating can address validity of terrestrial mass extinction theories**
  - **Current impact fluxes can be measured**
  - **Advanced telescope could accurately search for potential impactors**
- **Ice in lunar cold traps (if it exists) can provide history of volatiles in the solar system**
- **South Pole Aitken Basin is largest impact on Moon,**
  - **Can provide data on Earth-Moon cataclysms**
  - **Lower crust / upper mantle exposed**
- **Ancient galactic and solar particle fluxes can be determined from analysis of regolith**

Impact Flux



Composition of Polar Ice



Composition and Nature of Lunar Mantle

Lunar Pole - Mars Analogs

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Relevant Environmental and Operational Characteristics

- Low sun elevation provides nearly constant surface temperatures (-53º ± 10ºC)
- Region proximate to large permanently shadowed areas (-230 ºC) and potential location of ice deposits
- Line-of-site to Earth dependent upon terrain and lunar latitude libration

Human Mars Analog Objectives

- Testing of Mars surface equipment in lunar polar environment
  - Thermal, low-pressure, hypogravity, dusty conditions "similar" to Mars
  - May be relevant for EVA, habitation, life-support, mobility system testing
  - Science Operations
- Autonomous operations may be required when Earth out of line-of-site
- Lunar ice utilization technologies may be similar to those relating to Martian permafrost